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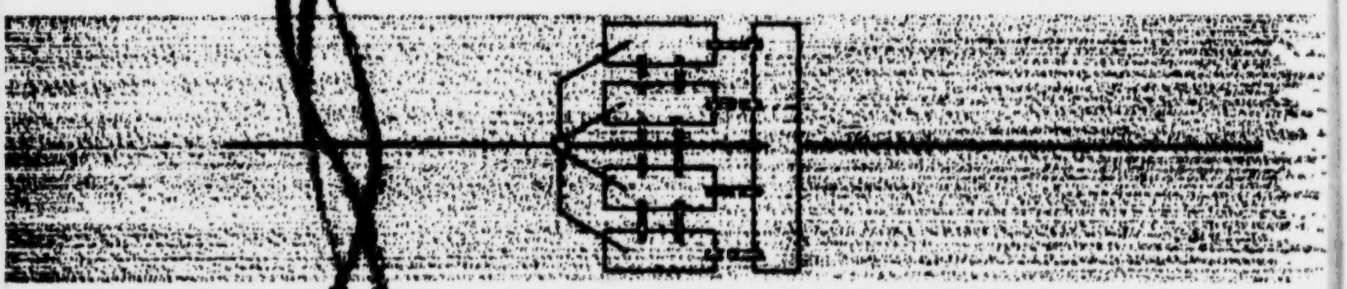
Waste Stabilization Pond Study

Lebanon, Ohio



U.S. DEPARTMENT OF HEALTH
EDUCATION, AND WELFARE
Public Health Service

WASTE STABILIZATION POND STUDY

LEBANON, OHIO

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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Division of Water Supply and Pollution Control

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ABSTRACT

This paper presents a study of the Lebanon, Ohio, waste stabilization ponds during each of the four seasons of the year. The objectives of the study were to evaluate waste stabilization pond performance, to determine the fate of pathogenic bacteria in terms of total and fecal coliform and fecal streptococci organisms, and to obtain supporting physical, chemical, and biochemical data. From this study it can be concluded that waste stabilization ponds in this area can effectively treat domestic wastes with a 5-day BOD loading rate of approximately 100 pounds per acre per day, that effective bacterial reductions can be achieved, and that waste stabilization pond effluents can be effectively chlorinated.

WASTE STABILIZATION POND STUDY

LEBANON, OHIO

SUMMARY

A study, conducted continuously for 10 days during each of the four seasons, was undertaken to evaluate waste stabilization pond performance and to determine the fate of pathogenic bacteria. The experimental ponds treated wastes emanating from a 200-man state institution; the wastes included those from the kitchen and from the laundry wherein the clothes of dairy farm workers were washed.

The two principal study ponds, Ponds I and III, were operated at depths of 4.5 and 3.5 feet and were 0.32 and 0.27 acre, respectively. The BOD loadings to Pond I ranged from 49 to 82 pounds per acre per day and those to Pond III from 117 to 194 pounds per acre per day. The ponds operated satisfactorily with virtually no odors despite the comparatively high loadings. (The winter was mild and ice cover did not persist for long periods.) Generally, the surface layer of water contained dissolved oxygen, but at lower depths oxygen was absent at times.

Minimum coliform reduction was 85.9 percent in winter and the maximum was 94.4 percent in autumn. Whereas fecal coliform reductions were similar, fecal streptococci reductions exceeded 97 percent.

BOD removals through Ponds I and III ranged from 73 to 79 percent and from 52 to 72 percent, respectively. With allowance for evaporation and seepage, the BOD removed by Pond I varied from 74 to 86 percent. The data indicate that treatment comparable to conventional secondary treatment was achieved at BOD loadings up to 50 pounds per acre per day and that greater than 50 percent reduction in BOD may be expected with loadings up to about 160 pounds per acre per day.

These waste stabilization ponds generally reduced soluble nutrients, a significant factor in evaluating effects of waste stabilization pond effluent on the receiving water. Nutrient patterns were similar to those reported in the literature.

The practical aspects of chlorinating waste stabilization pond effluent were explored. The data indicate that the Lebanon waste stabilization pond effluent can be effectively chlorinated by chlorine doses in the range of 7.5 to 10 milligrams per liter with a 15-minute contact time. Chlorination at the breakpoint was not effective since bacterial aftergrowths occurred. Chlo-

rination caused an increase in BOD of about 12 milligrams per liter, probably a result of algal cell destruction.

The dissolved oxygen data indicate that both ponds were essentially aerobic throughout most of the year; the hydrogen ion concentrations and water temperatures were in the expected ranges. Light and dark bottle data indicate the photosynthetic capacity of Pond I in the spring and demonstrate the correlation between oxygen production by algae and solar radiation.

After raw sewage was discharged into the waste stabilization ponds, the number of fungal species and colonies in the bottom muds greatly increased. It may be concluded that fungi have an important role in the breakdown of the organic constituents of raw sewage.

INTRODUCTION

The search for a more economical means of treating waste waters has led to the development of and subsequent wide acceptance of stabilization ponds. Initially, the ponds were essentially convenient holding basins with a minimum of engineering design. The paucity of both design criteria and history of operations and effectiveness led to requests that the U.S. Public Health Service undertake evaluation studies. The initial action led to a joint survey and field study by the Public Health Service and the Health Departments of North Dakota and South Dakota. [1,2] Concurrently, plans were made to study waste stabilization ponds in other geographical areas. These ponds were to be of sufficient size so that data could be extrapolated to full-scale operations with reasonable confidence. One experimental waste stabilization pond facility was established at Fayette, Missouri, in association with the State Health Department and local officials; studies on this installation have been reported elsewhere. [3] Another experimental waste stabilization pond facility was constructed through the cooperation of State and local officials at the Lebanon State Prison Farm, Lebanon, Ohio, approximately 25 miles north of the Robert A. Taft Sanitary Engineering Center. [4] This facility was designed to treat sewage from a 200-man dormitory and kitchen and laundry wastes. Four test cells of one-quarter acre each were designed for operation either in parallel or in series, with a final 2-acre cell to receive the effluents of the test cells (Figure 1). The cells could be operated at various liquid depths.

Domestic sewage included wastes from the kitchen and a laundry handling the work clothes of farm hands who worked with dairy and beef cattle and hogs in the fields and barns. The raw sewage was measured by a Parshall flume with a 3-inch throat

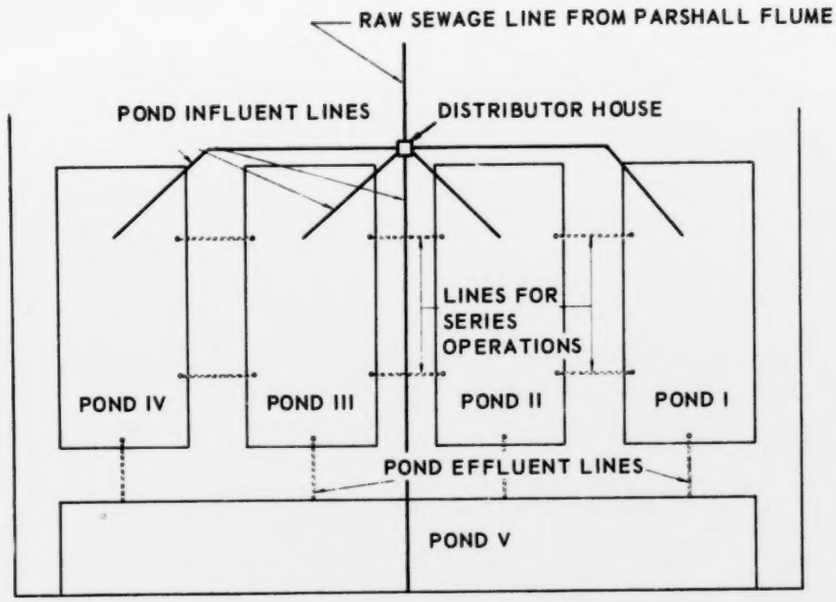

Figure 1. Plan view of Lebanon ponds and piping arrangement.

and a water level recorder. The waste then flowed for approximately 1,500 feet to a distribution box located on top of a dike at one end of the pond; the distribution box apportioned the flow to the cells in the desired ratio.

Topographical and other considerations necessitated locating these po ds in the flood plain of Shaker Creek, which flows through the institution property. Since the gravelly soil did not seal readily, Pond I was sealed with a black polyethylene film with excellent results. (Ponds II and IV were sealed by mixing bentonite clay into the dikes, since studies indicated that most seepage occurred through the dikes.) Pond III was allowed to seal naturally.

STUDY OBJECTIVES

In recent years, much data on waste stabilization pond design and operation have been accumulated and general acceptance of the precepts underlining the functioning of stabilization ponds has been achieved. Nevertheless, many unanswered questions such as the fate of pathogenic organisms in a waste stabilization pond, the chlorine demand of waste stabilization pond effluent, and the effectiveness of chlorination must be resolved to permit maximum use of this treatment device.

The objectives of this study were:

1. To evaluate seasonal performances of stabilization ponds in southwestern Ohio.

2. To determine the fate of pathogenic bacteria as measured in terms of total and fecal coliform and fecal streptococci organisms and to obtain supporting physical, chemical, and biochemical data.
3. To conduct other studies, such as the effectiveness of chlorinating stabilization pond effluent as resources permitted.

METHOD OF STUDY

The size and extent of the study required personnel, specialties, and facilities beyond the capabilities of any one discipline, although emphasis was on the bacteriological aspects. The project was a joint operation of the Technical Advisory and Investigations Section, Technical Services Branch, and the Microbiology Section, Basic and Applied Sciences Branch, both at the Robert A. Taft Sanitary Engineering Center. The Fungus Studies Laboratory of the Mycological Section, also of the Basic and Applied Sciences Branch, conducted studies of special interest to that Section.

The study was planned as a series of four intensive, continuous, 10-day sampling programs, one to be conducted during each of the four seasons, to define the mode of operation of the waste stabilization ponds over the year. The relatively stable population and daily routine of the institution would keep the raw-sewage load essentially the same over the year. Climatic conditions would be the main variables, and the four seasonal periods would include the extremes of the climatic factors.

Limiting the study to Ponds I and III presented an opportunity to study two ponds with relatively high BOD loadings for this area; Pond I was loaded in excess of about 50 pounds per acre per day, and Pond III, in excess of 115 pounds per acre per day.

STUDY ORGANIZATION

The intensive 10-day study periods required close coordination between the participating sections. Field personnel collected the samples and conducted onsite chemical and physical determinations of dissolved oxygen, pH, and temperature. Other samples were transported to the Robert A. Taft Sanitary Engineering Center for chemical, biochemical, and bacteriological analyses. The chemical and bacteriological samples were stored temporarily in a refrigerator at the site. Water temperature, maximum-minimum air temperature, and rainfall were measured during the seasonal studies.

All the biochemical and chemical analyses of the influent and effluent samples were made by chemists from the Technical Advisory and Investigations Section. Bacteriological examinations

of the influent and effluent samples were performed by the Microbiology Section.

PROCEDURES

SAMPLING

The raw waste was continuously sampled in proportion to flow as it entered the distribution box for dispersion among the ponds. Each composite sample represented a 6-hour interval; in this manner, 4 composite samples were obtained each day for biochemical and chemical analyses. Grab samples of raw waste for bacterial examination were collected every 2 hours and composited into a single sample every 4 hours. This constituted 6 samples per day or 60 samples of raw sewage per single study period.

The sampling points in Ponds I and III were located approximately two-thirds of the length of the ponds from the influent end. Platforms were extended approximately 15 feet over each pond, and from these points grab samples were collected every 2 hours at depths of 6 and 18 inches.

Equal portions of effluent for biochemical and chemical analyses were collected from the discharge line of each pond every 2 hours and composited every 6 hours into a single sample. Grab samples of effluent for bacteriological examination were collected every 2 hours and composited into a single sample every 4 hours; raw sewage samples were similarly collected.

SAMPLE CONTROL

The raw sewage samples for biochemical and chemical analyses were collected in 5-gallon carboys in iced containers. At the end of each 6-hour period, the carboy was thoroughly shaken and a gallon plastic jug was filled with the raw sewage. This jug was placed in a cooler until time for shipment to the laboratory. The effluent samples for biochemical and chemical analyses were held in 1-gallon plastic jugs; these were iced at all times. The bacteriological samples of raw sewage and effluent were kept in a cooler until time for shipment to the laboratory. The samples were kept iced while in transit.

The raw sewage and effluent samples were transported to the laboratories approximately every 12 hours, near noon and midnight. The samples brought in during the day were immediately analyzed, whereas the samples brought in at night were refrigerated until morning.

ANALYSES

The following biochemical and chemical determinations were made routinely on the influent and effluent collected during all four studies: BOD (5-day, 20°C), ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, and soluble phosphorus (orthophosphate or PO_4). Two additional determinations, Kjeldahl nitrogen and total solids, were made during the summer, fall, and winter studies.

The coliform examinations were made by the multiple-tube method using five replicates in three significant decimal dilutions, as described in the "confirmed MPN procedure" in Standard Methods. [5] The fecal coliform MPN was determined by confirming all positive presumptive lactose tubes in EC medium for lactose fermentation at 44.5°C in 24 hours. The streptococcal direct-count membrane filter method with the KF medium described by Kenner, Clark, and Kabler was used. [6]

RESULTS

PHYSICAL

Climatic Conditions

The Lebanon waste stabilization ponds are in an area of relatively mild climate. The normal monthly temperatures in Cincinnati, Ohio, range from 33.7° to 76.9°F with an annual average of 55.2°F (Table 1). [7] Over the 30-year period from 1931 to 1960, the normal monthly maximum temperatures varied from a low of 41.3°F in January to a high of 87.5°F in July. For the same 30-year period, the normal monthly minimum temperatures ranged from 26.1°F in January to 66.3°F in July.

The maximum and minimum temperatures for the Lebanon seasonal studies (Table 2) fall in the general range of normal values in the Cincinnati area, with the exception of the winter study, which was done during the last week in February and the first week in March. During the winter study, the temperature reached a maximum of 71°F and was 60°F several times, which was significantly higher than the normal monthly maximums of 43.4°F for February and 52.0°F for March (Table 1). [7] The U.S. Weather Bureau's Annual Ohio Survey (Table 3) shows unusually high temperatures of 67° to 73°F for February and March 1961 in the Cincinnati and Dayton area. Although the ponds were covered with ice during most of January 1961, the ice cover disappeared early in the next month.

Table 1. AVERAGE CINCINNATI TEMPERATURES FROM 1931 TO 1960[a]

Month	Avg max, °F	Avg min, °F	Avg, °F
January	41.3	26.1	33.7
February	43.4	26.7	35.1
March	52.0	33.3	42.7
April	64.4	43.9	54.2
May	74.9	53.5	64.2
June	83.8	63.0	73.4
July	87.5	66.3	76.9
August	86.4	64.9	75.7
September	80.3	57.6	69.0
October	68.9	46.8	57.9
November	53.2	36.0	44.6
December	42.6	27.9	35.3
Annual average			52.2

[a] Reference 7.

The ponds are in an area that has an annual average of 134 days with 0.01 inch or more of precipitation for an average annual total of 39.51 inches. Based on a 46-year period, the average number of days on which more than 0.01 inch of precipitation falls in April and August is 13 and 9 respectively.[7]

No rainfall was measured during the spring survey in April and the summer survey in August. A total of 0.25 inch fell during 1 day of the fall survey. It was calculated that, during the survey, rainfall on Pond I and its dikes totaled 2,510 gallons, and on Pond III and its dikes, 2,380 gallons.

Table 2. MAXIMUM AND MINIMUM AIR TEMPERATURES AT THE LEBANON SITE DURING THE STUDIES

Study	Date	Max, °F	Min, °F
Spring	4-5-60	49	38
	4-11-60	45	21
	4-12-60	63	37
	4-13-60	72	42
	4-14-60	75	42
	4-15-60		46
Summer	8-12-60	80	52
	8-14-60	75.5	51
	8-15-60	80	60
	8-16-60	75	60
	8-17-60	76	56
	8-21-60	85	56
	8-23-60	80	56
	8-24-60	79	60
Fall	10-31-60	63.5	49
	11-2-60	55	45
	11-4-60	58	29
	11-5-60	53	32.5
Winter	2-28-61	71	40
	3-1-61	71	42
	3-2-61	71	29
	3-3-61	39.5	25
	3-6-61	53	34
	3-8-61	53	26
	3-9-61	53	35
	3-10-61	40	25

Precipitation during 4 sampling days of the winter study totaled 1.14 inches. Thus, during the winter study, 11,450 gallons of rain fell on Pond I and its dikes and 10,850 gallons fell on Pond III and its dikes.

The Lebanon waste stabilization ponds are in an area that based on 46 years of record through 1961 [7] receives an average of 58 percent of the possible sunshine.

Table 3. CINCINNATI AND DAYTON TEMPERATURES DURING THE LEBANON STUDIES [a]

Date	Avg max, °F	Avg min, °F	Avg, °F	High, °F	Low, °F
		Cincinnati			
3-60	39	21	29.7	76	2
4-60	70	46	57.7	88	25
5-60	71	51	60.9	88	35
6-60	82	60	70.9	91	51
7-60	85	63	74.4	93	53
8-60	87	66	76.3	92	59
9-60	81	60	70.5	95	49
10-60	68	47	57.1	83	25
11-60	56	36	46.1	72	23
12-60	37	20	28.8	62	- 3
1-61	36	20	27.8	57	- 3
2-61	47	30	38.7	70	9
3-61	55	38	46.5	73	24
		Dayton			
3-60	35	18	26.7	73	1
4-60	66	43	54.7	87	23
5-60	68	50	59.0	83	34
6-60	80	59	69.4	88	52
7-60	83	62	72.6	90	53
8-60	85	65	75.3	91	58
9-60	80	59	69.5	94	45
10-60	66	45	55.6	82	26
11-60	52	34	43.3	69	20
12-60	33	16	24.4	61	- 8
1-61	31	16	23.5	52	- 8
2-61	43	28	35.8	67	4
3-61	52	35	43.7	70	20

[a]U.S. Weather Bureau Annual Ohio Survey.

Pond Operation

Pond I was 4.5 feet deep and had an area of 0.32 acre, whereas Pond III was 3.5 feet deep with an area of 0.27 acre. The raw sewage was so apportioned that Ponds I and II each received one-quarter of the total flow and Pond III received the other half. All

three ponds were operated in parallel. Pond IV did not receive any raw sewage during the year of study. This same flow distribution had been in effect for approximately 2 years prior to the spring study.

Table 4 presents the hydrologic data for the four seasonal studies. The average daily raw sewage flow varied from a minimum of 30,530 gallons during the winter study to a maximum of 44,288 gallons during the summer study.

Table 4. HYDROLOGIC AND PHYSICAL DATA FOR PONDS I AND III

Item	Study							
	Spring		Summer		Fall		Winter	
	Pond I	Pond III	Pond I	Pond III	Pond I	Pond III	Pond I	Pond III
Pond area, acres	0.32	0.27	0.32	0.27	0.32	0.27	0.32	0.27
Pond drainage, acres	0.37	0.35	0.37	0.35	0.37	0.35	0.37	0.35
Pond depth, ft	4.5	3.5	4.5	3.5	4.5	3.5	4.5	3.5
Pond volume, gal	374,300	253,950	374,300	253,950	374,300	253,950	374,300	253,950
Total sewage flow, gpd	a	a	a	a	a	a	a	a
Sewage flow to ponds, gpd	8,270	16,540	11,072	22,144	8,099	16,198	8,632	17,264
Rainfall, gpd	o	o	o	o	251	238	1,145	1,085
Sewage plus rain, gpd	8,270	16,540	11,072	22,144	8,350	16,436	9,777	18,349
Measured effluent, gpd	b	b	10,512	5,960	5,260	c	11,521	9,649[c]
Theoretical detention based on sewage flow, days	45	15	36	12	45	15	43	15
Liquid lost through evaporation and seepage, gpd	--	--	560	16,184	3,090	16,436	+1,744[d]	8,700[e]
V-notch weir used			60°	60°	45°	45°	30°	30°

[a]Total sewage flow, gpd
Spring: 33,080
Summer: 44,288
Fall: 32,396
Winter: 34,530

[b]Effluent was not measured.
[c]No effluent flow.
[d]Flow was greater than the measured influent.

[e]Figure covers only the first 5 days. The weir box was flooded during the second 5 days.

No effluent measurements were made during the spring study since it was assumed that the quantity of treated effluent discharged corresponded to the quantity of waste entering the ponds. During the other three studies V-notch weirs and water level

recorders were used to provide a continuous record of the discharge from Ponds I and III. For the summer study 60-degree V-notch weirs were used; 45-degree V-notch weirs were used for the fall study. Because the 60- and 45-degree V-notch weirs did not give the desired accuracy, 30-degree V-notch weirs were used for the winter study. Even though the rate of discharge from each pond varied during the course of the day, the flow during each of the four 6-hour composite periods was relatively constant so that it was not necessary to composite in proportion to flow.

Ponds I and III each had effluent flows during the entire summer study period. As shown in Table 4, 560 gpd of liquid was lost from Pond I, and 16,184 gpd from Pond III, through evaporation and seepage.

During the fall study there was no effluent from Pond III. There had been a period of dry weather before the beginning of the fall study and seepage plus evaporation kept the water level in Pond III below the overflow structure. Samples collected during this period were taken at the surface near the overflow pipe.

It was impossible to obtain a measurement of the effluent flow from Pond III during the last week of the winter study because the weir box was flooded; the effluent flow was greater than the influent flow during the period.

There is a discrepancy between inflow and outflow for Pond I (Table 4). Rainfall averaged 1,145 gpd on the pond surface and the dikes during the study. When the effluent flows are corrected for rainfall, the discrepancy between inflow and outflow is reduced from 2,889 to 1,744 gpd. The discrepancy may result in part from inherent errors in the flow measurements.

BACTERIOLOGICAL

There were no significant differences in the coliform densities for raw sewage during spring, summer, and autumn (Table 5). A slight reduction in numbers of coliforms occurred during the winter period. Fecal coliform densities were between 79,000 and 92,000 per 100 milliliters in spring, summer, and winter. In the autumn series, the fecal coliforms increased to 2.65 million per 100 milliliters. Fecal streptococcal densities varied from 2.1 to 4.1 million per 100 milliliters in the sewage.

Pond I effluent showed a reduction in coliform population from 85.9 percent in winter to 94.4 percent in autumn. Fecal coliform reductions were between 87.9 percent and 98.3 percent. The greatest reduction occurred in the numbers of fecal streptococci; they were reduced 97.0 to 99.8 percent during the four seasons.

Table 5. BACTERIAL REDUCTION IN TWO LEBANON WASTE STABILIZATION PONDS

Season	Bacterial test	Raw sewage	Pond I		Pond III	
		Density, millions/ 100 ml	Density, millions/ 100 ml	Reduction, %	Density, millions/ 100 ml	Reduction, %
Spring	Confirmed coliform	3.20	0.265	91.8	0.180	94.4
Summer		3.30	0.350	89.4	1.100	66.7
Fall		3.30	0.185	94.4	0.640	80.7
Winter		2.40	0.340	85.9	0.692	71.2
Spring	Fecal coliform	0.92	0.049	94.7	0.045	95.2
Summer		0.81	0.014	98.3	0.073	91.0
Fall		2.65	0.071	97.4	0.530	80.0
Winter		0.79	0.096	87.9	0.208	73.7
Spring	Fecal streptococci	4.10	0.010	99.8	0.190	95.4
Summer		2.10	0.017	99.2	0.038	98.2
Fall		3.40	0.098	97.2	0.430	87.4
Winter		2.70	0.082	97.0	0.155	94.3

For Pond III the minimum coliform removal of 66.7 percent occurred in summer after a maximum removal of 94.4 percent was recorded in the spring. Fecal coliform reduction ranged from 73.7 percent to 95.2 percent for the year. Fecal streptococci reductions varied from 87.4 percent to 98.2 percent.

The importance of frequent sampling of sewage during a 24-hour period is shown in Table 6. These numbers are based on the 10-day geometric mean values for samples collected during the spring study; they represent a relative number of bacteria discharged into the ponds, since flow rates in gallons per period sampled were not used in this table. Total coliform densities reached peaks at 6 am and noon. Both peaks preceded the fecal streptococcal maximum values by 2 hours. A considerable fluctuation in the streptococcal densities in the untreated sewage occurred; the 8 am and 2 pm values represented the high levels. The fecal coliform peaks occurred at 8 am and 6 pm. The 8 am rise corresponded in time to that for fecal streptococci, but the 6 pm rise was 4 hours after the afternoon fecal streptococcal peak values. Inspection of the data for either of the two pond effluents reveals only a slight tendency toward peak bacterial densities at specific times.

This study points up the value of frequent sampling of raw sewage. Taking one sample every 2 hours with two such samples composited every 4 hours into a single bacteriological sample is desirable. Such a sampling schedule was found to be essential because of the fluctuations in densities of indicator microorganisms in both sewage and effluents during a 24-hour period. Past results of once-a-day grab sampling of raw sewage are uncertain because once-a-day sampling frequently leads to inaccurate interpretations and thus should be avoided.

Since soil abounds with many anaerobic and aerobic spore-forming bacteria and since symbiosis is common, it is possible that some of the confirmed coliform test results contained false positive reactions. In a survey of 251 soil samples, large discrepancies were frequently noted in a comparison between the confirmed and completed MPN results on the same samples. [8] The raw sewage in this study contained both domestic sanitary wastes and laundry wastes; the laundry washed work clothing exposed to manure and field soils. Because of the possibility of numerous false positive reactions from organisms associated with soil, the completed test is recommended in future studies for greater accuracy in measuring total coliform density and in calculating reduction efficiency. Data presented here also suggest that the use of the fecal coliform test and the fecal streptococcus procedure may yield more valuable information and be more specific for removals of warm-blooded animal pollution than the use of a total coliform procedure alone.

Table 6. GEOMETRIC MEAN VALUES FOR POLLUTION INDICATORS BY SAMPLE PERIODS (millions per 100 milliliters)

Sampling time	Total coliforms			Fecal coliforms			Fecal streptococci		
	Raw sewage	Pond I effluent	Pond III effluent	Raw sewage	Pond I effluent	Pond III effluent	Raw sewage	Pond I effluent	Pond III effluent
Midnight+2am+4am	4.60	0.170	0.220	1.10	0.033	0.044	0.89	0.10	0.21
6am	5.50	0.200	0.150	1.50	0.035	0.036	2.40	0.11	0.19
8am	2.70	0.210	0.390	1.60	0.045	0.162	14.00	0.14	0.42
10am+noon	5.00	0.250	0.200	0.78	0.071	0.053	3.00	0.16	0.19
2pm	4.00	0.360	0.200	0.90	0.059	0.065	7.10	0.15	0.12
4pm	2.00	0.130	0.110	0.42	0.026	0.027	3.50	0.06	0.11
6pm	3.10	0.170	0.130	1.30	0.039	0.034	3.50	0.06	0.15
8pm+10pm	3.80	0.140	0.140	1.10	0.052	0.035	2.80	0.10	0.16

BIOCHEMICAL AND CHEMICAL

Biochemical Oxygen Demand

The 5-day BOD load to Pond I varied from 49 to 82 pounds per acre per day and that to Pond III varied from 117 to 194 pounds per acre per day (Tables 7 and 8, Figures 2 and 3). These loadings are high when compared with loadings of 20 to 40 pounds per acre per day, which is the generally accepted 5-day BOD loading criterion for this general area of the country.

Pond I demonstrated little difference in efficiency in the reduction of BOD concentrations throughout the four studies; the range was from 73 to 79 percent. Pond III showed a range of BOD removals from 52 to 72 percent. During the summer study, however, the mean 5-day BOD concentration in the effluent was essentially the same for both ponds, which indicates that BOD loadings of about 200 pounds per acre per day may be applied to waste stabilization ponds in this area during the summer months. In general, the pond that received the lighter 5-day loading and was deeper produced better effluent in terms of BOD than the shallower more heavily loaded pond. The efficiency of Pond I in terms of pounds of 5-day BOD varied from 74 to 86 percent.

Ammonia Nitrogen

The mean ammonia-nitrogen concentration in the raw wastes ranged from 5.2 to 10.4 milligrams per liter for the winter and spring studies, respectively (Tables 7 and 8, Figures 2 and 3). The minimum and maximum values obtained during the entire study were 2.1 and 28.2 milligrams per liter for the fall and spring, respectively.

In the effluent from Pond I, the mean ammonia-nitrogen concentration ranged from 3.1 to 10.3 milligrams per liter for the summer and winter, respectively. The mean ammonia-nitrogen concentration decreased 42 percent in the spring, 55 percent in the summer, and 38 percent in the fall, and increased 98 percent in the winter (Tables 7 and 8, Figures 2 and 3).

The mean effluent concentration of ammonia nitrogen from Pond III was lower than the mean values in the effluent from Pond I; the values in Pond III ranged from 2.5 milligrams per liter for the fall to 8.2 for the winter. The mean ammonia-nitrogen concentration decreased 64 percent in the spring, 59 percent in the summer, and 55 percent in the fall, and increased 58 percent in the winter.

Table 7. BIOCHEMICAL AND CHEMICAL DATA FOR POND I

Determination	Study period	Mean influent concentration, mg/l	Mean influent load, lb/acre/day	Mean influent load, lb/acre/day	Mean effluent concentration, mg/l	Mean effluent, lb/day	Removal concentration, %	Removal lb/day, %
BOD	Spring	222	16	49	50	a	78	a
	Summer	225	26	82	60	6	73	77
	Fall	280	22	68	60	3	79	86
	Winter	224	19	59	57	5	75	74
NH_3-N	Spring	10.4	0.6		6.0	a	42	a
	Summer	6.6	0.6		3.1	0.3	55	50
	Fall	5.5	0.3		3.4	0.1	38	67
	Winter	5.2	0.4		10.3	1	+98[b]	+150[b]
NO_2-N	Spring	0.022	0.0015		0.020	a	9	a
	Summer	0.030	0.0028		0.023	0.0021	23	25
	Fall	0.017	0.0012		0.037	0.0016	+118[b]	+33[b]
	Winter	0.076	0.0054		0.010	0.0007	87	87

NO_3-N	Spring	0.21	0.013		0.14	a	33	a
	Summer	0.08	0.009		0.06	0.005	25	44
	Fall	0.13	0.010		0.07	0.003	46	70
	Winter	0.25	0.02		0.06	0.005	76	75
Kjeldahl-N	Spring[c]							
	Summer	20	1.9		14.5	1.3	28	32
	Fall	21.2	1.4		14.7	0.7	31	50
	Winter	19.9	1.4		18.4	1.8	7	+29
Soluble Phosphorus	Spring	11.9	0.8		6.5	a	46	a
	Summer	3.1	0.3		2.6	0.2	17	33
	Fall	4.5	0.3		4.8	0.2	+ 7[b]	33
	Winter	4.6	0.4		7.9	0.7	+72[b]	+75[b]
	Spring[c]							
	Summer	684	73	227	562	50	18	32
	Fall	636	46	143	552	24	13	48
	Winter	619	48	149	498	50	20	+ 4[b]

[a]Effluent was not measured. [b]Plus sign indicates percentage is increased. [c]Determinations were not made.

Table 8. BIOCHEMICAL AND CHEMICAL DATA FOR POND III

Determination	Study period	Mean influent concentration mg/l	Mean influent load, lbs/day	Mean influent load, lbs/acre/day	Mean effluent concentration, mg/l	Removal concentration, %
BOD	Spring	222	32	117	89	60
	Summer	225	52	194	64	72
	Fall	280	44	161	135	52
	Winter	224	38	132	99	56
NH_3-N	Spring	10.4	1.2		3.7	64
	Summer	6.6	1.2		2.7	59
	Fall	5.5	0.6		2.5	55
	Winter	5.2	0.8		8.2	+58[a]
NO_2-N	Spring	0.022	0.0030		0.0100	55
	Summer	0.030	0.0056		0.0040	87
	Fall	0.017	0.0024		0.0109	36
	Winter	0.076	0.0108		0.0107	86

NO_3-N	Spring	0.21	0.026		0.14	33
	Summer	0.08	0.018		0.06	25
	Fall	0.13	0.020		0.06	54
	Winter	0.25	0.040		0.08	68
Kjeldahl-N	Spring[b]					
	Summer	20	3.8		14.5	28
	Fall	21.2	2.8		24.3	+15[a]
	Winter	19.9	2.8		20.6	+ 4[a]
Soluble Phosphorus	Spring	11.9	1.6		5.4	55
	Summer	3.1	0.6		2.9	7
	Fall	4.5	0.6		5.5	+ 2[a]
	Winter	4.6	0.4		7.8	+70
Total Solids	Spring[b]					
	Summer	684	146	539	577	16
	Fall	636	92	339	717	+13[a]
	Winter	619	96	353	552	11

[a] Plus sign indicates percentage is an increase. [b] Determinations were not made.

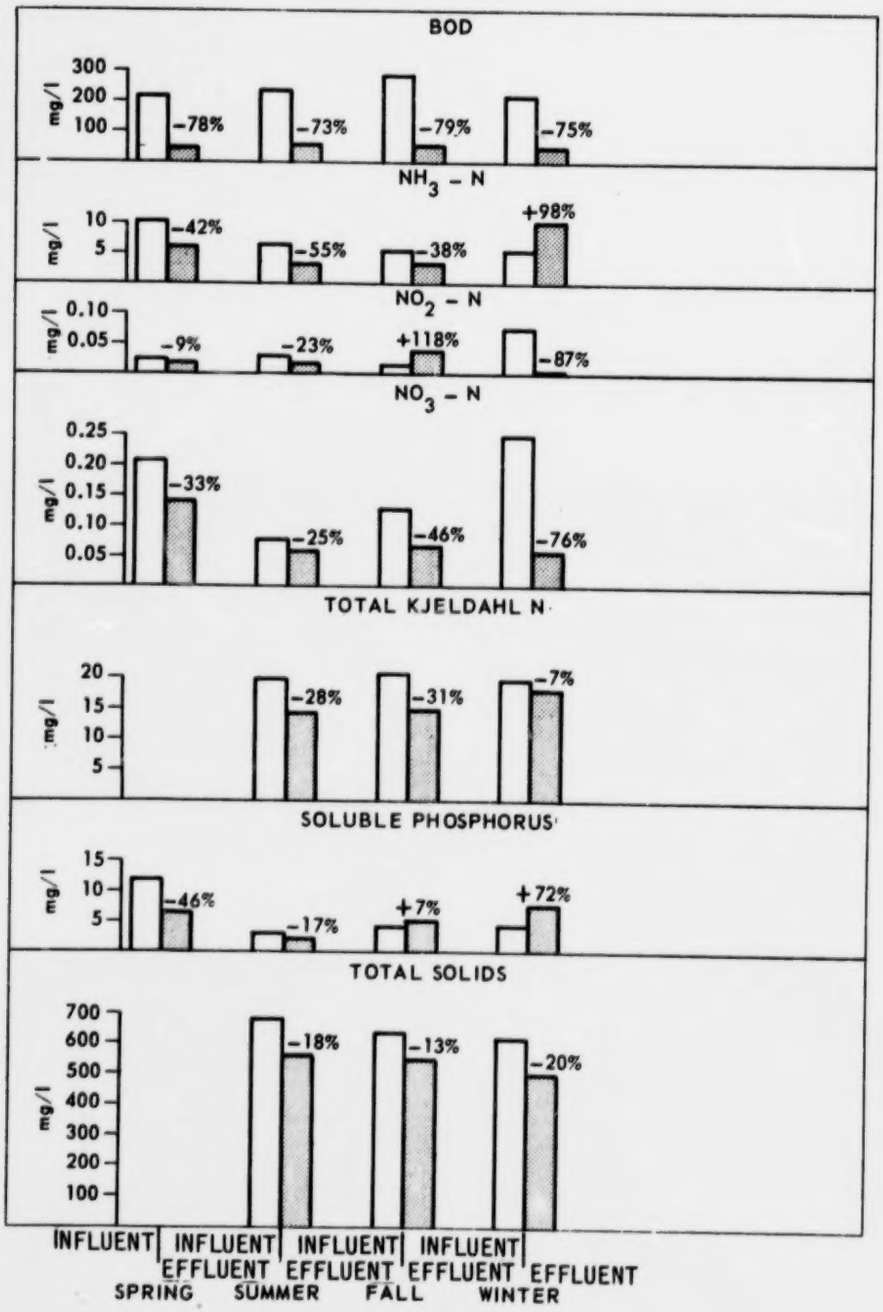

Figure 2. Pond I biochemical and chemical data
(Note: + % = percent increase; −% = percent decrease).

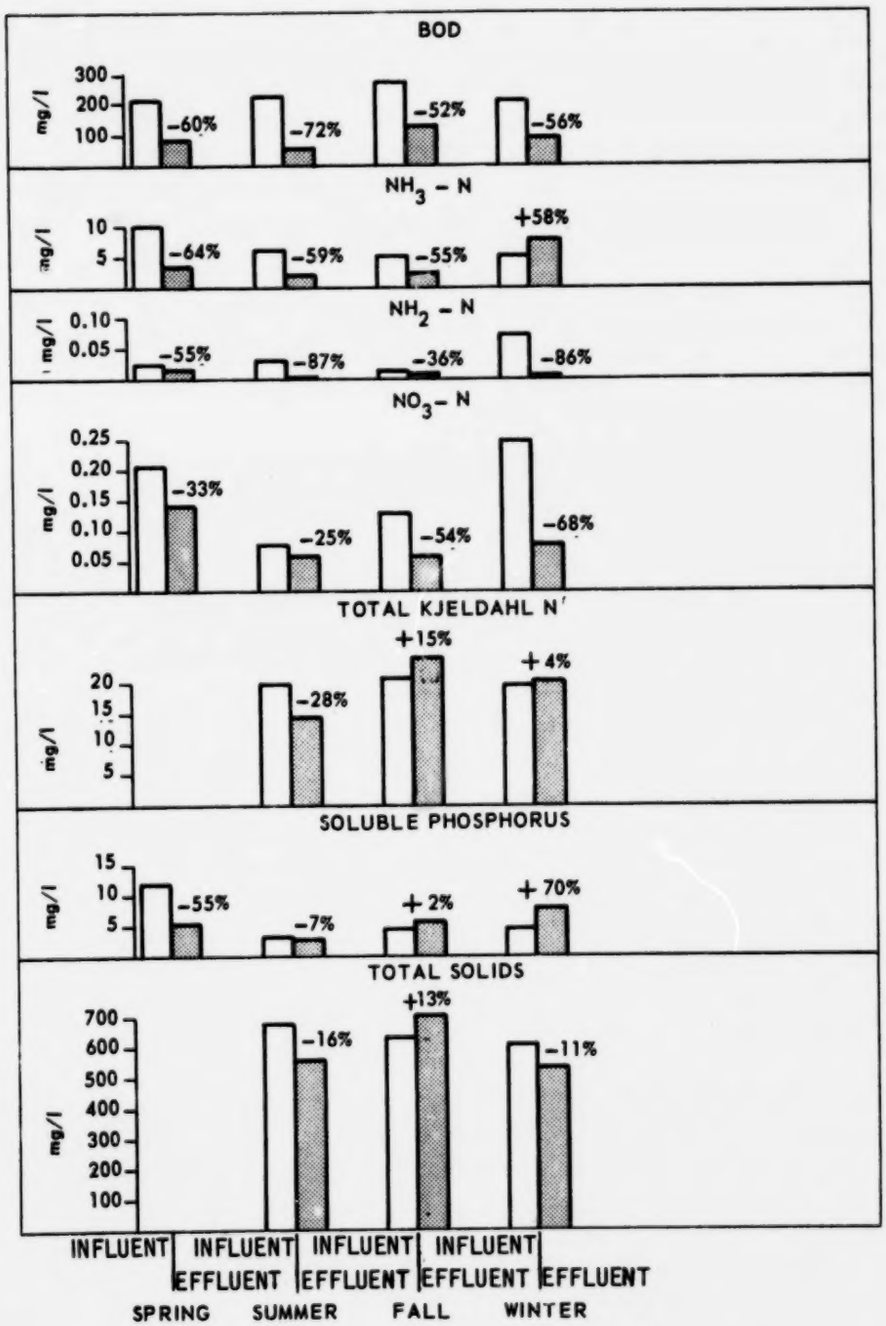

Figure 3. Pond III biochemical and chemical data .
(Note: +% = percent increase; -% = percent decrease).

The mean ammonia-nitrogen concentrations in both ponds decreased in the spring, summer, and fall and increased in the winter. In the presence of excess oxygen produced by the algae in waste stabilization ponds, nitrification occurs and ammonia nitrogen is oxidized to nitrite nitrogen and nitrate nitrogen. In addition, during periods of rapid algal growth, the ammonia nitrogen is consumed by the algal cells; thus, the concentrations are reduced in the ponds, as occurred during the spring, summer, and fall. During winter months, however, when there are lower temperatures and reduced algal growth and photosynthesis, an increase in the mean ammonia-nitrogen concentration may be anticipated, as was shown by the increases of the mean ammonia-nitrogen concentration in the ponds during the winter study period.

Mean influent loads of ammonia nitrogen in terms of pounds per day to both ponds are presented in Tables 7 and 8. These values ranged from 0.3 to 0.6 pound per day and 0.6 to 1.2 pounds per day for Ponds I and III, respectively. There was a variation of 0.1 to 1.0 pound per day of ammonia nitrogen in the effluent from Pond I.

Nitrite Nitrogen

The mean nitrite-nitrogen concentration in the raw sewage ranged from 0.017 milligram per liter during the fall study to 0.076 for the winter (Tables 7 and 8, Figures 2 and 3).

The mean nitrite-nitrogen concentration in Pond I decreased 9 percent in the spring and increased 118 percent in the fall. Pond III effluent demonstrated a reduction in mean nitrite-nitrogen concentration ranging from 36 to 87 percent.

Nitrate Nitrogen

The mean nitrate-nitrogen concentration in the raw sewage varied from 0.08 milligram per liter in the summer survey to 0.25 in the winter. The mean nitrate-nitrogen concentration was reduced in both ponds; the reductions ranged from 25 to 76 percent and 25 to 68 percent for Ponds I and III, respectively. Both ponds achieved the greatest removal of nitrate nitrogen during the winter. Both ponds produced comparable mean nitrate-nitrogen concentrations in the effluent.

Kjeldahl Nitrogen

The Kjeldahl determination was performed during the summer, fall, and winter studies. The mean Kjeldahl nitrogen concentration in the raw waste was 20.0, 21.2, and 19.7 milligrams per liter for the summer, fall, and winter, respectively.

The effluent from Pond I showed a mean Kjeldahl nitrogen concentration of 14.5, 14.7, and 18.4 milligrams per liter in the summer, fall, and winter, respectively. The mean Kjeldahl nitrogen concentration decreased in all three studies.

In Pond III effluent, the mean Kjeldahl nitrogen concentration increased 15 percent and 4 percent in the fall and winter, respectively. In the summer, the mean concentration decreased 28 percent, as did the mean concentration in Pond I.

The tables show that Pond I was loaded at the mean rate of 1.4 to 1.9 pounds per day of Kjeldahl nitrogen. In terms of pounds per day, Kjeldahl nitrogen in the effluent decreased in the summer and fall, but increased 29 percent in the winter. Flow measurements during the winter period indicated that there was about 1,600 gpd more effluent than influent for Pond I; this and lower temperatures probably account for the 29 percent increase.

Soluble Phosphorus

The mean soluble phosphorus concentration of 11.9 milligrams per liter in the raw waste for the spring study was relatively high when compared with 3.1, 4.5, and 4.6 milligrams per liter for the summer, fall, and winter studies, respectively (Tables 7 and 8, Figures 2 and 3).

The data indicate that the mean soluble phosphorus concentration in both ponds decreased in the spring and summer, when much of the soluble phosphorus was being utilized by the algal cells. Both pond effluents, however, showed increases in mean soluble phosphorus concentrations in the fall and winter. The increases were 72 percent in Pond I and 70 percent in Pond III in the winter when algal growth was at a minimum and the soluble phosphorous was not being utilized as rapidly as during the spring and summer.

Pond I received as much as 0.8 pound per day of soluble phosphorus and Pond III as much as 1.6 pounds per day during the spring, and considerably less during the other three seasons. The relatively high mean soluble phosphorus concentration and the greater poundage of soluble phosphorus in the raw waste during the spring study were probably related to the nature of farm work in the spring when the fields were being fertilized and the soluble phosphorus was washed from the farm workers' clothing.

Nutrients support tremendous growths of algae, which in turn are responsible for the production and maintenance of dissolved oxygen in aerobic waste stabilization ponds. Mackenthun and McNabb[9] showed that a 20-acre waste stabilization pond in Wisconsin maintained an average mass of algal material weighing 9 tons. The

algal cells remove the nutrients from solution and convert them into cellular materials. Many of the algal cells die and settle to the bottom, where they combine with the bottom sediments and undergo decomposition, which, in turn, results in a liberation of nutrients.

During periods when the pH is in the alkaline range (8.5 to 10.5) and dissolved oxygen is present, phosphorus may be precipitated. When the dissolved oxygen becomes depleted in the bottom materials and the pH returns to about neutral, the phosphorus may redissolve and become available to the algae.[9] With a reduced algal population during the winter months, less soluble phosphorus is utilized; this probably explains why there was an increase in the soluble phosphorus concentration in the effluents from Ponds I and III during the winter.

Bogen[10,11] states: "Theoretically an oxidation pond should be capable of very high efficiencies of phosphorus removal. In order to realize this potential, active photosynthesis and high pH conditions, or both, must prevail for some time prior to discharge."

Algal cells may be discharged in waste stabilization pond effluents. When these algal cells die and decompose, the nutrients again become available for plant consumption. It is possible that the nutrient load from a waste treatment plant might tip the balance and create a problem of excessive fertilization in the receiving waters; this would result in algal blooms and an overabundance of rooted higher aquatic plants.

Total Solids

The mean total solids concentration in the raw waste varied from 619 milligrams per liter for the winter survey to 684 for the summer survey (Tables 7 and 8, Figures 2 and 3).

In Pond I the mean concentration of total solids decreased from 13 to 20 percent in the three periods. Pond III achieved reductions in the mean total solids concentration of 16 percent for the summer and 11 percent for the winter, but showed an increase of 13 percent for the fall.

Pond I had a total solids loading ranging from 143 to 227 pounds per acre per day, and Pond III had a total solids loading ranging from 339 to 539 pounds per acre per day.

The mean total solids discharged from Pond I varied from 24 to 50 pound per day, or about 7.5 tons per year. A significant portion of the total solids in waste stabilization pond effluents is algal cells, which contribute in some degree to the oxygen demand as measured by the standard 5-day 20°C BOD determination.[12, 13, 14]

Dissolved Oxygen

The dissolved oxygen, water temperature, and pH data collected from Ponds I and III during the seasonal studies are presented in Tables 9, 10, 11, and 12. These tables, when reviewed daily for each study, show the extreme values for dissolved oxygen, water temperature, and pH at depths of 6 and 18 inches.

Pond I was functioning aerobically at depths of 6 and 18 inches during the entire spring study; maximum dissolved oxygen values were 28.4 milligrams per liter at 6 inches and 20.5 at 18 inches (Tables 9 and 10). Pond III also was functioning aerobically at depths of 6 and 18 inches during the spring study (Tables 11 and 12); however, early in the morning on several days there were periods of 2 to 4 hours when dissolved oxygen was not present in quantities sufficient to be measured. Maximum dissolved oxygen values of 35.2 milligrams per liter at 6 inches and 22.0 at 18 inches clearly reveal photosynthetic oxygenation.

During the summer study dissolved oxygen levels dropped to zero very consistently at 6 and 18 inches in both ponds. The dissolved oxygen level at 18 inches in both ponds remained at zero for the last few days of the study, but photosynthesis was sufficient to maintain aerobic conditions in at least the upper 6 inches of the ponds during the daylight hours. The maximum dissolved oxygen concentrations at 6 inches were 43.5 milligrams per liter in Pond I and 33.3 in Pond III.

In general, the dissolved oxygen levels in both ponds were lower during the fall than during the spring and summer. It is apparent from the oxygen levels, that the photosynthetic rate in the ponds was substantially less in the fall than during the spring and summer. The minimum dissolved oxygen value was zero at both depths in Pond III, and approached or attained zero consistently at both depths in Pond I. The maximum dissolved oxygen concentrations at 6 and 18 inches in Pond I were 25.3 and 8.8 milligrams per liter, respectively. For the same depths in Pond III, the maxima were 18.7 and 9.9 milligrams per liter, respectively.

The dissolved oxygen levels during the winter study again consistently reached zero at 6 and 18 inches in both ponds. There were several days when the dissolved oxygen was zero and both ponds apparently were operating under anaerobic conditions. Photosynthetic activity on other days, however, produced maximum dissolved oxygen concentrations of 14.4 milligrams per liter at 6 inches and 14 at 18 inches in Pond I. Pond III showed essentially the same photosynthetic effect; the maximum dissolved oxygen concentrations were 14.3 milligrams per liter at 6 inches and 11.1 at 18 inches.

Table 9. DISSOLVED OXYGEN, TEMPERATURE, AND pH VALUES IN POND I AT 6 INCHES

	Dissolved oxygen, mg/l		Water temperature, °C		pH	
Date	min	max	min	max	min	max
4-3-60	4.4	7.2	12	14	7.0	7.8
4-4-60	2.4	12.1	10	14	7.2	9.0
4-5-60	2.9	10.9	9	12	-	-
4-6-60	3.7	8.2	8	11	-	-
4-7-60	3.7	17.4	8	12	-	-
4-8-60	5.0	12.1	10	12	7.8	8.6
4-10-60	6.8	9.7	9	12	8.4	8.9
4-11-60	7.8	20.0	7.5	10	7.5	8.8
4-12-60	6.1	26.4	10	18	8.3	9.1
4-13-60	12.7	28.4	14	20	7.3	9.5
4-14-60	10.9	27.8	17	20	8.3	9.4
4-15-60	12.4	18.9	17	19	8.2	9.1
Spring means			12.3		8.3	
8-12-60	8.3	27.4	24	26	-	-
8-13-60	1.1	43.5	21	30	7.9	9.7
8-14-60	1.0	43.4	22	30	8.0	9.2
8-15-60	0.0	26.6	24	28	8.5	9.5
8-16-60	0.0	30.4	22	28	6.9	9.6
8-17-60	0.0	26.1	23	29	8.6	9.6
8-19-60	1.2	32.5	26	28	9.6	10.0
8-20-60	0.0	18.4	24	28	8.8	9.0
8-21-60	0.0	18.0	22	28	8.7	9.6
8-22-60	0.0	9.3	24	26	8.7	9.4
8-23-60	0.0	28.2	24	28	8.4	9.5
8-24-60	0.0	13.0	24	28.5	8.4	9.0
Summer means			25.7		9.1	

Table 9. (Continued)

	Dissolved oxygen, mg/l		Water temperature, °C		pH	
Date	min	max	min	max	min	max
10-23-60	4.4	5.5	14	14	-	-
10-24-60	0.9	9.0	10	14	-	-
10-25-60	1.4	25.3	10	15	7.6	9.2
10-26-60	0.3	11.4	11.5	14	8.0	8.8
10-27-60	0.0	1.4	12	14	7.8	8.6
10-28-60	0.0	4.9	12	15	7.9	8.7
10-30-60	4.8	8.6	15	16	-	-
10-31-60	0.0	3.1	12.5	15	8.0	8.5
11-1-60	0.0	7.1	13	14	8.1	8.4
11-2-60	0.0	6.3	12	14	8.0	8.4
11-3-60	0.1	7.8	10	12	7.8	8.3
11-4-60	0.8	10.4	11	14	7.8	8.8
Fall means			13.1		8.3	
2-26-61	0.0	0.0	7	9.5	-	-
2-27-61	0.0	0.0	7	12	7.6	8.2
2-28-61	0.0	0.6	7.5	9.5	7.6	8.0
3-1-61	0.0	0.2	7	10	7.4	8.0
3-2-61	0.0	1.5	6	9	7.2	8.0
3-3-61	0.0	4.9	8	12	7.4	8.1
3-5-61	4.7	7.05	14	16	-	-
3-6-61	1.6	6.4	13	16	7.6	8.2
3-7-61	0.0	11.7	12	15	7.7	8.2
3-8-61	0.0	4.4	10	13	7.5	8.0
3-9-61	1.9	6.8	6	9	7.4	8.0
3-10-61	0.8	14.4	6	10	7.4	8.3
Winter means			10.2		7.8	

Table 10. DISSOLVED OXYGEN, TEMPERATURES, AND pH VALUES IN POND I AT 18 INCHES

	Dissolved oxygen, mg/l		Water temperature, °C		pH	
Date	min	max	min	max	min	max
4-3-60	1.6	7.6	12	14	7.0	8.2
4-4-60	0.6	12.2	10	14	7.1	8.5
4-5-60	2.0	9.4	9	13	-	-
4-6-60	3.0	9.1	7	11	-	-
4-7-60	3.8	11.5	8	11	-	-
4-8-60	5.6	11.6	10	12	7.2	8.3
4-10-60	4.1	10.2	9.5	10	8.5	9.1
4-11-60	7.6	19.0	8	10	7.3	8.6
4-12-60	2.5	10.3	9.5	13	8.3	8.8
4-13-60	0.8	20.5	13	19	7.3	9.4
4-14-60	2.3	16.4	15	19	8.5	9.4
4-15-60	4.0	16.2	16	18	8.5	8.9
Spring means			12.3		8.3	
8-12-60	0.04	0.1	24	25	-	-
8-13-60	0.0	4.6	22	26	7.55	8.8
8-14-60	0.05	1.3	22.5	24.5	8.1	8.5
8-15-60	0.0	4.6	23	26	7.1	8.8
8-16-60	0.0	0.6	22	25	8.1	8.7
8-17-60	0.0	1.0	23	28	8.55	8.8
8-19-60	0.0	1.6	24	26	8.7	8.8
8-20-60	0.0	1.3	24	26	8.3	9.0
8-21-60	0.0	2.4	22	25.5	7.9	9.3
8-22-60	0.0	0.0	24	26	8.6	8.9
8-23-60	0.0	0.0	22	29	8.1	8.9
8-24-60	0.0	0.0	22.5	26	7.8	8.7
Summer means			24.5		8.5	

Table 10. (Continued)

	Dissolved oxygen, mg/l		Water temperature, °C		pH	
Date	min	max	min	max	min	max
10-23-60	0.0	4.3	14	14	-	-
10-24-60	1.0	8.7	11	14	-	-
10-25-60	1.2	6.6	9	14	7.0	8.5
10-26-60	0.2	8.5	11	14	8.0	8.7
10-27-60	0.0	1.7	11.5	14	7.9	8.4
10-28-60	0.0	1.2	12	14	7.8	8.3
10-30-60	0.0	2.1	15	15	-	-
10-31-60	0.0	2.2	12	15	8.1	8.3
11-1-60	0.0	6.8	12	14	7.9	8.3
11-2-60	0.0	6.1	12	13	7.3	8.3
11-3-60	0.0	7.7	10	12	7.4	8.2
11-4-60	0.45	8.8	10.5	13	7.7	8.6
Fall means			12.2		8.0	
2-26-61	0.0	0.0	7	9.5	-	-
2-27-61	0.0	0.0	7	10	7.5	8.3
2-28-61	0.0	0.0	7.5	9.5	7.5	7.9
3-1-61	0.0	1.6	6	10	7.2	7.8
3-2-61	0.0	1.5	6	10	7.0	7.7
3-3-61	0.0	3.4	7	12	7.3	7.85
3-5-61	0.0	0.0	12	14	-	-
3-6-61	0.0	5.4	13	16	7.4	7.8
3-7-61	0.0	11.4	13	15	7.4	8.0
3-8-61	0.0	4.1	9.5	13	7.3	8.2
3-9-61	1.6	6.5	6	9	7.3	8.3
3-10-61	4.4	14.1	5	10	7.2	8.2
Winter means			9.9		7.7	

Table 11. DISSOLVED OXYGEN, TEMPERATURE, AND pH VALUES IN POND III AT 6 INCHES

	Dissolved oxygen, mg/l		Water temperature, °C		pH	
Date	min	max	min	max	min	max
4-3-60	0.0	6.1	12	14	7.8	8.2
4-4-60	0.0	13.5	12	16	7.3	9.0
4-5-60	1.8	11.8	10	12	-	-
4-6-60	4.8	10.8	6	12	-	-
4-7-60	5.5	21.9	7	13	-	-
4-8-60	8.5	20.1	10	13	7.5	8.8
4-10-60	8.4	24.9	10	12	9.2	9.3
4-11-60	5.3	23.5	7.5	11	8.8	9.2
4-12-60	8.3	35.2	9.5	18	8.7	9.5
4-13-60	5.6	28.4	13.5	20	8.9	9.5
4-14-60	1.7	16.1	16	20	8.3	9.3
4-15-60	0.0	5.7	16	20	8.5	8.9
Spring means			12.9		8.7	
8-12-60	0.05	6.9	24	25	-	-
8-13-60	2.5	17.9	22	27	7.6	8.8
8-14-60	0.3	33.3	22.5	29	8.0	9.3
8-15-60	2.0	24.4	24	28	8.5	9.0
8-16-60	0.0	27.4	22	28	7.9	9.3
8-17-60	0.0	26.4	23	29	8.3	9.2
8-19-60	1.7	10.2	24.5	27.5	8.9	9.2
8-20-60	0.0	19.6	24	28	7.8	9.2
8-21-60	0.0	25.5	24	28	7.4	9.2
8-22-60	0.0	10.0	23	28	8.4	8.9
8-23-60	0.0	29.8	23	29	7.9	9.3
8-24-60	0.0	25.2	24	30	8.0	9.2
Summer means			25.7		8.6	

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Table 11. (Continued)

	Dissolved oxygen, mg/l		Water temperature, °C		pH	
Date	min	max	min	max	min	max
10-23-60	1.8	3.7	12	13	-	-
10-24-60	0.0	9.5	10	13	-	-
10-25-60	0.0	18.7	8.5	15	7.0	8.6
10-26-60	0.0	5.5	11	14	7.7	8.5
10-23-60	0.0	0.4	13	14	7.85	8.5
10-28-60	0.0	5.8	13	15	7.8	8.5
10-30-60	0.0	1.0	15	17	-	-
10-31-60	0.0	1.9	14	16	7.8	8.2
11-1-60	0.0	8.2	12	14	7.6	8.2
11-2-60	0.0	6.6	12	13	7.5	8.1
11-3-60	0.0	8.2	10	12	7.4	8.2
11-4-60	0.0	10.6	10	13.5	7.5	8.3
Fall means			12.5		8.0	
2-26-61	0.0	0.7	8	9.6	-	-
2-27-61	0.0	4.1	7	12	7.3	7.9
2-28-61	0.0	0.0	8	10	7.0	7.8
3-1-61	0.0	0.0	8	10.5	7.4	7.7
3-2-61	0.0	1.3	8	10	7.0	7.7
3-3-61	0.0	8.7	8	15	7.0	7.9
3-5-61	0.0	0.7	15	16	-	-
3-6-61	0.0	3.1	14.5	18	7.4	7.7
3-7-61	0.0	6.3	13.5	14.5	7.3	8.0
3-8-61	0.0	3.3	9	13	7.2	8.0
3-9-61	0.0	6.9	6	9	7.2	8.2
3-10-61	2.5	14.3	5	9	7.3	8.3
Winter means			10.7		7.6	

Table 12. DISSOLVED OXYGEN, TEMPERATURE, AND pH VALUES IN POND III AT 18 INCHES

	Dissolved oxygen, mg/l		Water temperature, °C		pH	
Date	min	max	min	max	min	max
4-3-60	0.0	3.55	12	13	7.6	8.5
4-4-60	0.0	3.4	11	14	7.6	8.3
4-5-60	1.3	11.9	10	12	-	-
4-6-60	4.7	11.8	7	11	-	-
4-7-60	6.25	21.6	8	13	-	-
4-8-60	7.8	18.2	10	12	7.4	8.8
4-10-60	6.95	22.9	10	11	9.0	9.4
4-11-60	7.8	20.7	7	10.5	7.6	9.2
4-12-60	3.8	12.4	10	18	8.3	9.2
4-13-60	2.4	22.0	13	19	7.5	9.5
4-14-60	0.9	14.3	17	20	8.8	9.3
4-15-60	0.0	6.45	17	20	8.5	8.8
Spring means			12.7		8.5	
8-12-60	3.9	18.6	24	24	-	-
8-13-60	0.0	9.7	22	25	7.65	8.3
8-14-60	0.0	6.4	22.5	26	7.9	8.5
8-15-60	0.0	6.7	24	26	8.2	9.3
8-16-60	0.0	2.8	23	28	7.5	8.6
8-17-60	0.0	3.1	23	26	8.2	8.7
8-19-60	0.0	0.0	24	27	8.2	8.6
8-20-60	0.0	0.4	24	28	8.2	8.8
8-21-60	0.0	0.0	22.5	27	8.1	8.5
8-22-60	0.0	0.0	23	27	7.9	8.5
8-23-60	0.0	0.0	23	26.5	7.9	8.4
8-24-60	0.0	0.0	24	27	-	-
Summer means			24.9		8.3	

Table 12. (Continued)

	Dissolved oxygen, mg/l		Water temperature, °C		pH	
Date	min	max	min	max	min	max
10-23-60	1.8	3.6	12	12	-	-
10-24-60	0.0	8.5	10	13	-	-
10-25-60	0.0	0.6	7.5	12	6.8	8.0
10-26-60	0.0	2.3	10.5	13	7.2	8.3
10-27-60	0.0	0.0	12.5	14	7.5	8.5
10-28-60	0.0	0.0	13	14	7.5	8.0
10-30-60	0.0	0.0	15	15	-	-
10-31-60	0.0	1.9	14	15.5	7.7	8.2
11-1-60	0.0	7.3	12	14.5	7.6	8.1
11-2-60	0.0	5.7	12	14	7.6	8.1
11-3-60	0.0	7.8	10	12	7.3	8.1
11-4-60	0.0	9.9	10.5	12	7.6	8.3
Fall means			12.5		7.8	
2-26-61	0.0	0.3	8	9.5	-	-
2-27-61	0.0	0.9	8	10	7.5	7.6
2-28-61	0.0	1.6	7	10	7.3	7.6
3-1-61	0.0	0.0	6	10	7.3	8.3
3-2-61	0.0	1.2	7	12	7.2	7.9
3-3-61	0.0	6.0	8	14	7.0	7.9
3-5-61	0.0	0.0	15	15	-	-
3-6-61	0.0	2.7	14	18	7.3	8.0
3-7-61	0.0	3.3	13	15	7.3	7.8
3-8-61	0.0	3.9	9.5	12	7.2	8.0
3-9-61	0.0	6.9	5	9	7.3	7.8
3-10-61	2.45	11.1	4	8	7.3	8.0
Winter means			10.3		7.6	

It is evident from the dissolved oxygen data that both ponds were essentially aerobic most of the year, and were capable of satisfactory performance under the prevailing loadings and climatic conditions.

Odors

A problem that must be given considerable thought in designing a waste stabilization pond installation is the possibility of putrid odors, especially during the spring thaw in the northern section of the country. This factor is probably the most important criterion to be considered in the design of a waste stabilization pond. Even with the relatively high BOD loadings applied to the Lebanon waste stabilization ponds and with some ice cover during each of the three winters the ponds were in operation, there were no odor problems associated with the ponds in the spring; however, the winters were relatively mild and there were no extended periods of complete snow and ice cover. Under severe winter conditions, the applied BOD loadings probably would have been too high, especially for Pond III.

Temperature

The daily minimum and maximum and the mean water temperatures for each study are presented in Tables 9, 10, 11, and 12. The highest mean temperatures occurred during the summer study, and the lowest, during the winter study. The temperatures during the winter study also indicate that there was no ice cover at that time; as noted previously, the minimum-maximum air temperature range was above normal and precluded the retention or formation of ice cover. There had, however, been ice cover up to 1.5 inches thick on both ponds during December 1960 and January 1961.

Hydrogen Ion Concentration (pH)

Photosynthesis by algae utilizes free carbon dioxide. When the supply of free carbon dioxide is exhausted, the algae extract carbon dioxide from the bicarbonate salts and the pH rises; it is possible to attain a pH value as high as 10 during the day when a high rate of photosynthesis occurs.

The highest mean pH values for Pond I (9.1 at 6 inches and 8.5 at 18 inches) occurred during the summer study (Tables 9 and 10); this was the period of maximum photosynthetic activity, as indicated by the dissolved oxygen ranges. The lowest mean pH values for Pond I (7.8 at 6 inches and 7.7 at 18 inches) occurred during the winter study, which was the period of minimum photosynthetic activity. The spring and fall studies of Pond I fell between the two extremes and were characterized by similar mean pH values and ranges of dissolved oxygen concentrations at 6 inches.

The sequence of photosynthetic activity in Pond III was somewhat different (Tables 11 and 12): the highest mean pH values (8.7 at 6 inches and 8.5 at 18 inches) occurred during the spring study, which according to the range of dissolved oxygen was the maximum photosynthetic period. The fall and winter studies show lower mean pH values and less variation in the dissolved oxygen concentrations, as would be expected.

SPECIAL STUDIES

OXYGEN PRODUCTION

The light and dark bottle technique was used to evaluate photosynthetic oxygen production in the upper 6 inches of Pond I on March 4 and 19, 1959 (Figure 4). At the time of the study, the pond had been receiving an average daily load of about 60 pounds per acre per day of 5-day 20°C BOD over a period of 9 months.

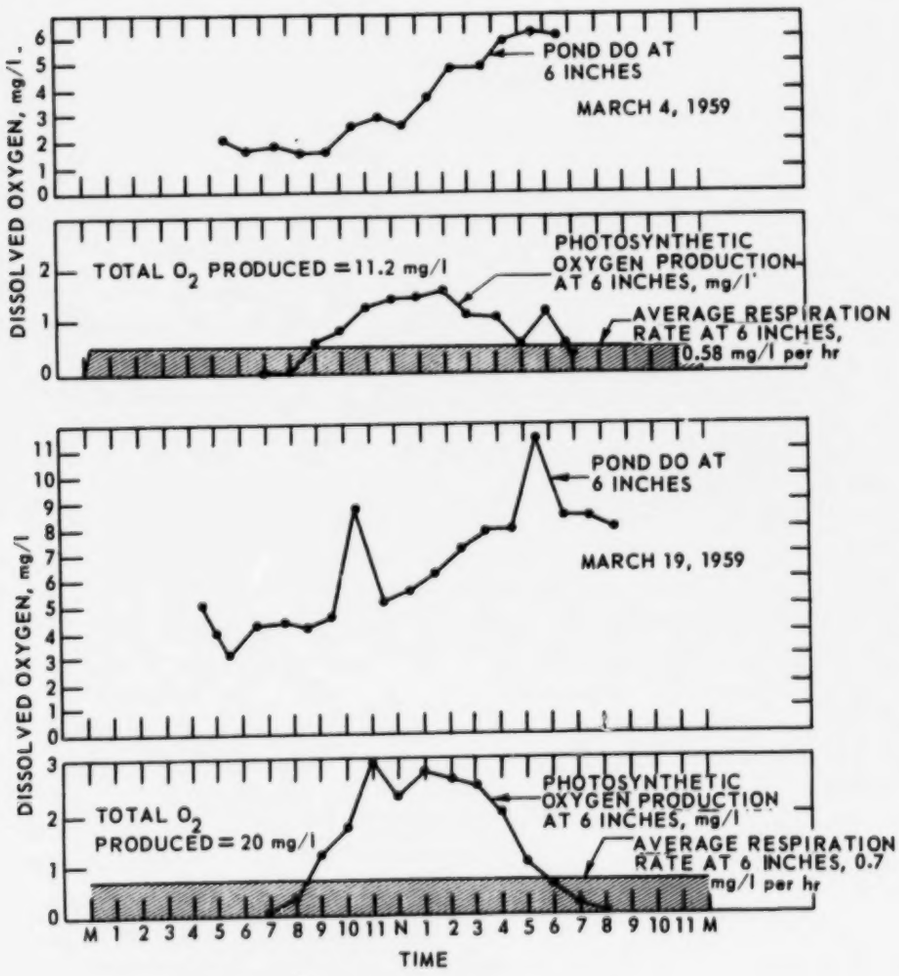
DISSOLVED OXYGEN, mg/l
POND DO AT 6 INCHES
MARCH 4, 1959
TOTAL O_2 PRODUCED = 11.2 mg/l
PHOTOSYNTHETIC OXYGEN PRODUCTION AT 6 INCHES, mg/l
AVERAGE RESPIRATION RATE AT 6 INCHES, 0.58 mg/l per hr
DISSOLVED OXYGEN, mg/l
POND DO AT 6 INCHES
MARCH 19, 1959
TOTAL O_2 PRODUCED = 20 mg/l
PHOTOSYNTHETIC OXYGEN PRODUCTION AT 6 INCHES, mg/l
AVERAGE RESPIRATION RATE AT 6 INCHES, 0.7 mg/l per hr
M 1 2 3 4 5 6 7 8 9 10 11 N 1 2 3 4 5 6 7 8 9 10 11 M
TIME

Figure 4. Oxygen production studies, Pond I, March 4 and 19, 1959.

In a 13-hour period on March 4, 1959, an estimated 11.2 milligrams per liter of oxygen was produced and an estimated 7.4 milligrams per liter of oxygen was utilized; this resulted in a net gain of 3.8 milligrams per liter. The mean water temperature was 8.3°C.

The average hourly rate of oxygen utilization determined by this technique was 0.58 milligram per liter. With this assumed average rate over the 24-hour period, the oxygen demand for the day was 13.9 milligrams per liter; this resulted in a photosynthesis-to-respiration ratio (P/R) of 0.8. Thus, even with a net gain in oxygen during the daylight hours, there was an oxygen deficit of 2.7 milligrams per liter for the 24-hour period. If this situation had continued for an extended period, the pond probably would have become septic. If atmospheric reaeration had not overcome this deficit, anaerobic decomposition with its accompanying problems would have occurred.

Data from March 19, 1959, show a somewhat different situation. There was an estimated total oxygen production of 20.0 milligrams per liter over a 14-hour daylight period with a net oxygen gain of 10.3 milligrams per liter. The oxygen utilization was estimated to be 9.7 milligrams per liter for the same period with an average hourly rate of 0.7. The mean temperature was 8.5°C or 0.3°C higher than on March 4, 1959. An oxygen demand of 16.8 milligrams per liter for the 24-hour period was obtained by using the calculated hourly average of 0.7. This gave a P/R ratio of 1.2. On this particular day there was an excess of 3.2 milligrams per liter of oxygen produced over the 24-hour oxygen demand.

These data cannot be extrapolated directly to the pond because of environmental differences between the bottles and the pond. The Dakota studies[1] point out several of these differences: "During daylight, especially on warm, calm days, temperature decreases with depth, commonly as much as 10.8°F in 3-1/2 feet. Such gradients, which are generally formed before noon, disappear during high winds and after sunset, so that temperature is fairly uniform with depth at such times. The algae, also, are not distributed uniformly with depth, but tend to concentrate toward the surface during daytime and again become more uniformly distributed at night." An additional difference is that carbon dioxide may become a limiting factor as the day progresses. Bartsch and Allum[15] point out another difference, "Dissolved oxygen concentrations are more transient in the ponds than in the test bottles." For example, during round-the-clock studies at Lebanon, Ohio, the dissolved oxygen concentration at 6 inches was observed to vary from zero at night to about 43 milligrams per liter during the day. Still another difference is that during periods of supersaturation, oxygen is lost to the atmosphere, and as night approaches, less available oxygen

is present than calculated. In summary, in spite of these deviations, which preclude exact simulation of pond conditions, the light and dark bottle test data give a reasonable estimate of photosynthetic oxygen productivity.

SOLAR RADIATION VS OXYGEN PRODUCTION

Several physical factors play a significant role in the sucessful operation of waste stabilization ponds; solar radiation with its relationship to the photosynthetic mechanism of the algae is one of the most important.

Figure 5 shows the relationship between oxygen production by algae and by solar radiation on 2 separate days at Lebanon. During daylight hours on March 4, 1959, there was a total accumulation of 733 gram-calories per square centimeter (g-cal/cm^2). Of this quantity, 256 g-cal/cm^2 was within the visible light range of 4,000 to 7,000 Angstroms, which is the usable portion of light energy. As noted previously, the accumulated oxygen produced amounted to 11.2 milligrams per liter for the 13-hour period. On March 19, 1959, a total accumulation of 955 g-cal/cm^2 was measured; 355 g-cal/cm^2 was within the visible light range. More solar energy and oxygen were accumulated on this day than on March 4, 1959; however, the latter accumulation was over a 14-hour period.

CHLORINATION

A limited laboratory study was conducted to determine the chlorine dosages required for effective control of coliform organisms in the effluent of one of the Lebanon ponds. It is believed that the results obtained are applicable to full-scale ponds when applied with the knowledge about chlorination of sewage plant effluents developed over the years.

The initial studies were developed to ascertain the general range of chlorine demand, which is the difference between the dosage and the residual. Four samples, each consisting of 6-hour composites, were collected in late summer 1960 and treated with chlorine in five dosages of 10, 20, 30, 40, and 50 milligrams per liter, the contact time was 15 minutes. The results are shown in Figure 6; some of the curves indicate breakpoints that occurred at dosages from about 25 to 40 milligrams per liter. After dosages of 40 milligrams per liter, the breakpoints were exceeded.

To eliminate uncontrolled sample variation, a subsequent test was made on a single grab sample collected in early spring 1961. The sample was treated with 5, 10, 25, 50, and 100 milligrams per liter of chlorine in three series at contact times of 15, 30, and 60

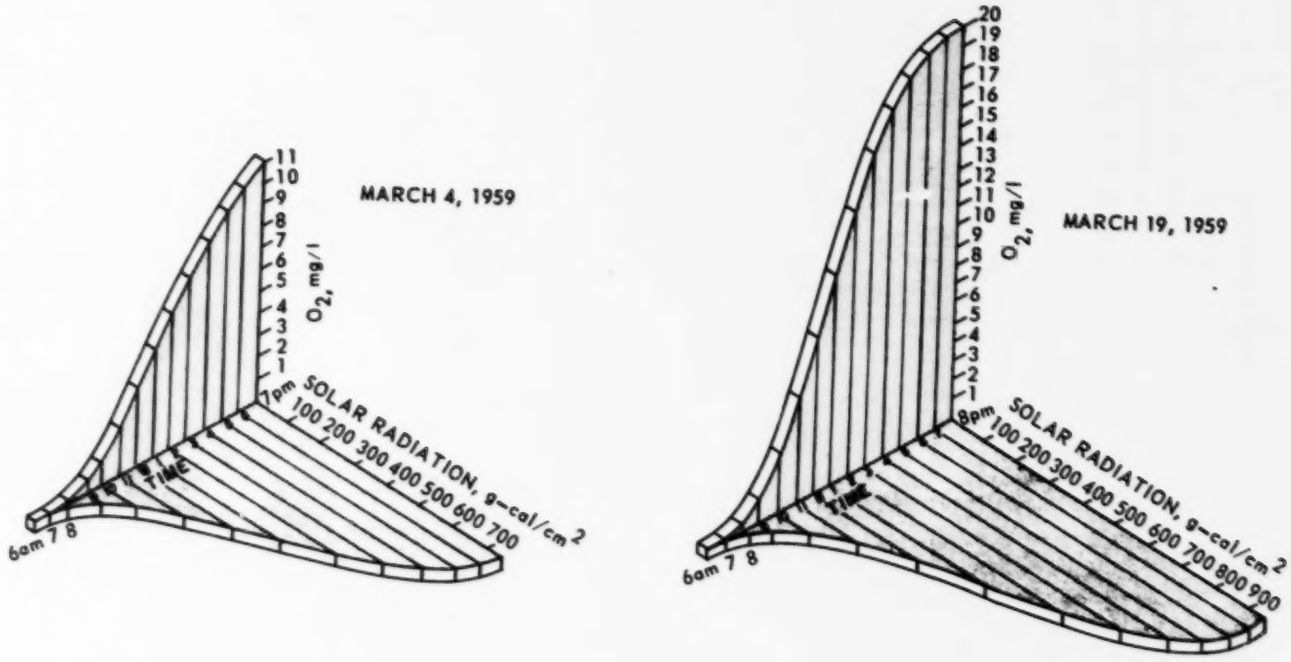

Figure 5. Cumulative oxygen production at 6 inches vs cumulative solar radiation, Pond I.

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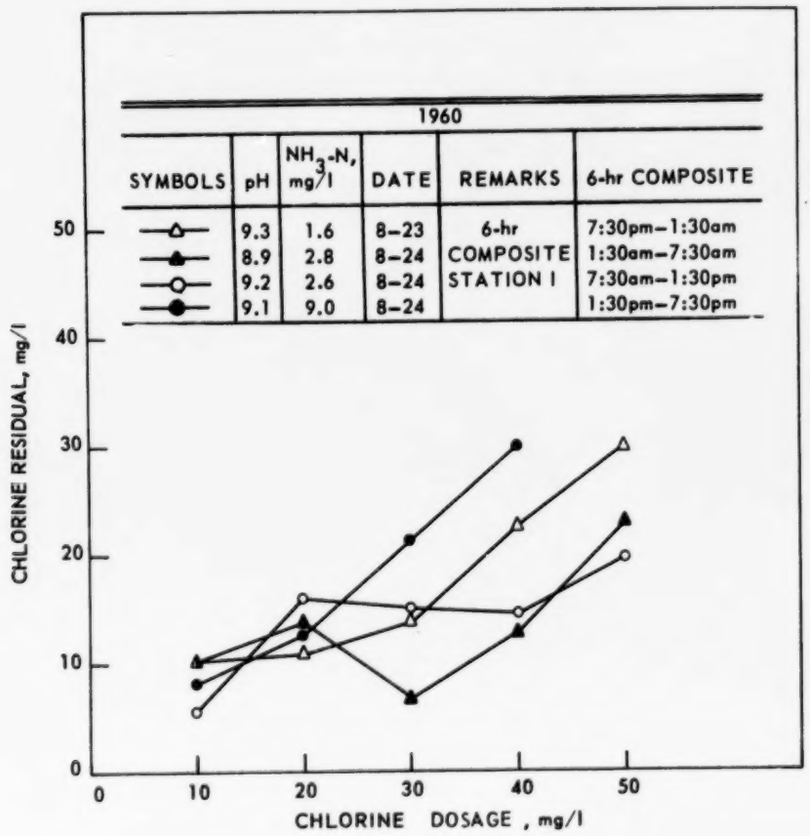

Figure 6. Chlorine demand after 15-minute contact time.

minutes. Tests for residual chlorine, BOD, and coliform organisms were run on the samples, before and after treatment. These data are presented in Table 13 and Figures 7 and 8.

Figure 7 presents a typical chlorine curve with a pre-breakpoint peak reached at a dosage of 25 milligrams per liter; the residual was about 17 milligrams per liter. The 50-milligrams-per-liter dosage indicates a breakpoint and the residual dropped to about 7 milligrams per liter. The 100-milligrams-per-liter dosage was considerably beyond the breakpoint, showing residuals of 38, 45, and 50 milligrams per liter, which varied with the contact times of 15, 30, and 60 minutes. In the effective range, variation among the three contact periods was small, indicating that a 15-minute contact time was adequate.

Table 13. COLIFORM IN POND EFFLUENT AFTER CHLORINATION, EXPERIMENT 1

Cl_2 applied, mg/l	Initial MPN/100 ml	Contact time				
		15 min	30 min	60 min	72 hr[a]	8 days[a]
		MPN/100 ml				
0	33,000					
5.0		330	45	20	20	20
10.0		20	20	20	20	20
25.0		20	20	20	20	20
50.0		20	20	20	2300	330
100.0		20	20	20	20	20

[a] Aftergrowth evaluation.

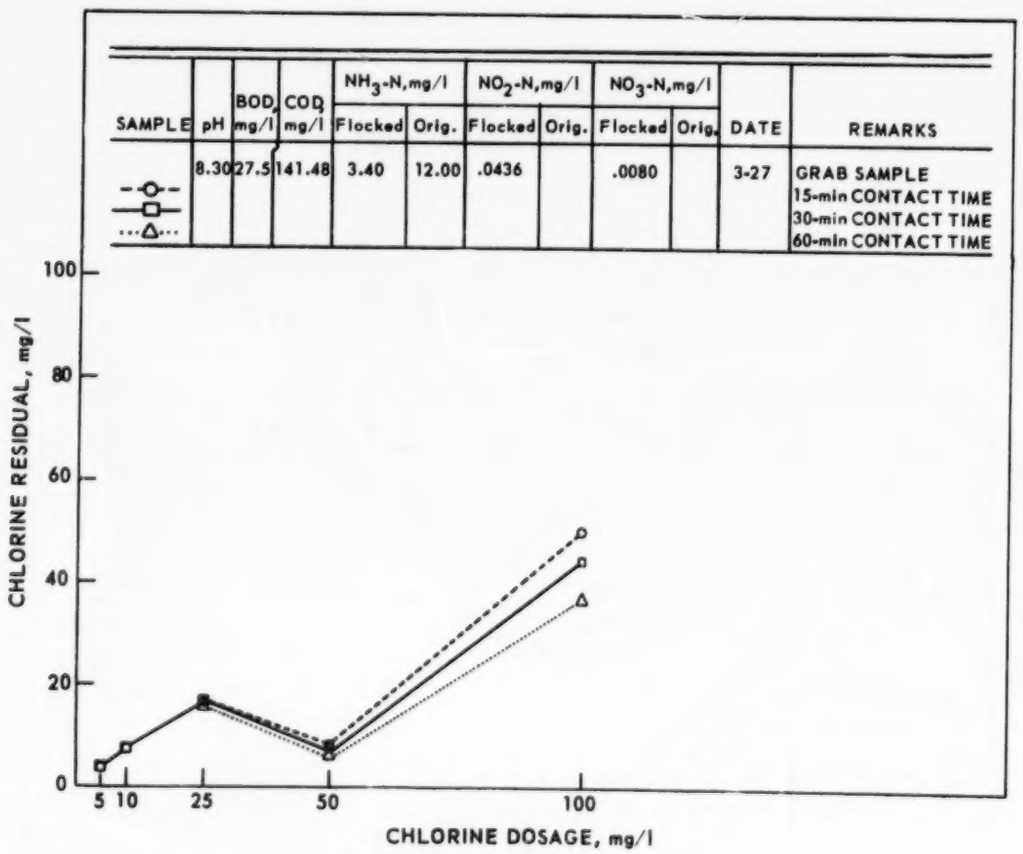

Figure 7. Typical curves showing chlorine dosage vs chlorine residual and a pre-breakpoint peak.

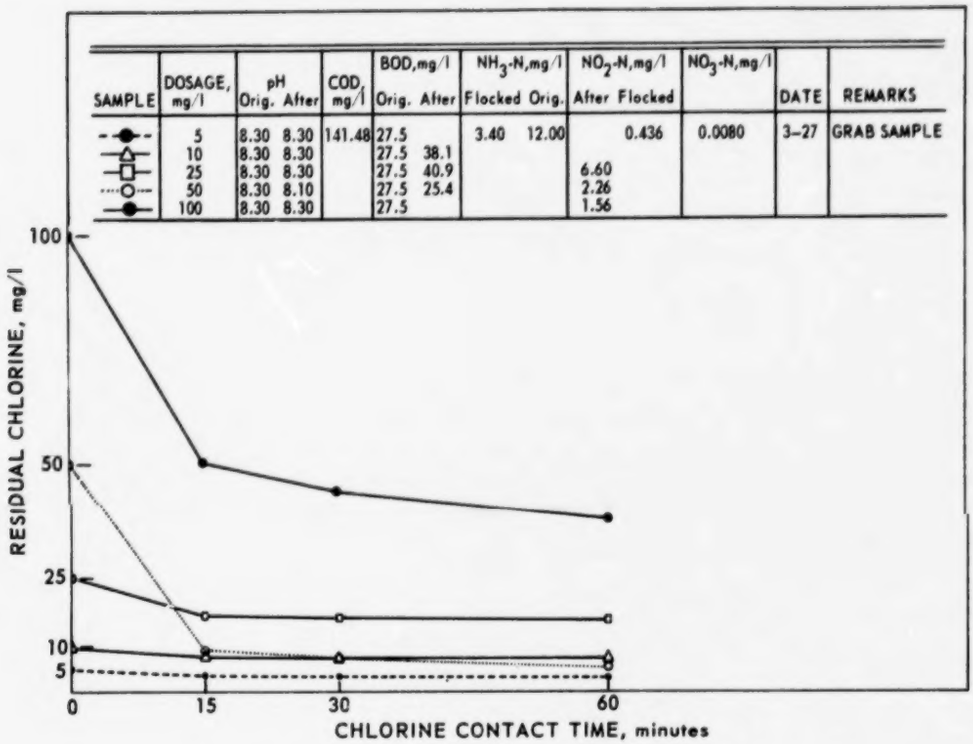

Figure 8. Chlorine contact time vs chlorine residual.

These data were also plotted to show contact time versus residual chlorine (Figure 8). This series of curves shows that a contact time much longer than 15 minutes is not required. It also shows breakpoint action: the residual of the 50-milligrams-per-liter dosage dropped in 15 minutes to much less than the residual of the 25-milligrams-per-liter dosage.

The effect of breakpoint chlorination is dramatically shown by the coliform and BOD results. Table 13 shows the coliform results after designated chlorine dosages with 15, 30, and 60-minute contact times, and after 72 hours and 8 days to show possible aftergrowths. These samples were not dechlorinated to provide a more severe environment than a stream that normally dissipates the chlorine. With 15 minutes or more contact time, dosages of 10 milligrams per liter or more of chlorine accomplished effective bacterial kill. The 50-milligrams-per-liter dosage that approached the breakpoint showed, however, aftergrowths of nearly 10 percent of the initial concentration of 33,000 MPN in 72 hours. In this sample, bacterial growth continued, although at a reduced level, for 8 days.

The BOD of the effluent and chlorine treated samples were (Figure 8):

Chlorine dosage, mg/l	BOD after chlorination, mg/l
0	27.5
10	38.1
25	40.9
50	25.4

Some interesting interpretations can be placed on these data. Pond effluents contain algae; many investigators believe that the BOD of waste stabilization pond effluents reflects the algal density. This concept may be correct, but the above data indicate that many algae may survive the 5-day incubation in the dark. They undoubtedly consume oxygen and have some influence on the BOD. Effective chlorination disrupts the algal cells, however, and they become available to bacterial degradation. With the 10-milligrams-per-liter dosage, therefore, the BOD increased to 38.1 milligrams-per-liter, and with the 25-milligrams-per-liter dosage, it increased to 40.9, virtually the same value. With the 50-milligrams-per-liter dosage, however, which fortuitously was in the breakpoint range, the BOD after treatment was 25.4 milligrams per liter, or slightly less than in the untreated sample. This is reasonable since the breakpoint is that point at which the chlorine reacts completely with the nitrogenous compounds. At that point, the chlorine residual is at a minimum and algae are not destroyed, and thus the BOD remains essentially unchanged.

These results are further supported by the bacterial data. It is interesting to speculate that the occasional coliform that remains after chlorination of drinking water may result from chance chlorination at the breakpoint brought about by fixed chlorination of water with a varying chlorine demand.

For better definition of the minimum chlorine dosage for effective bacterial control, another grab sample of pond effluent was dosed with chlorine at 1, 2.5, 5, 7.5, and 10 milligrams per liter with contact times of 5, 15, and 30 minutes. The BOD of this sample was 42.1 milligrams per liter and the coliforms MPN was 7,900 per 100 milliliters.

The results of this run are shown in Figure 9 and Table 14. The plot of chlorine dosage versus chlorine residual gave a rather uniform increase of residual with increase of dosage, with only minor variations among the different contact times. Effective bacterial kill resulted from 7.5 milligrams per liter of chlorine at 30 minutes of contact or from 10 milligrams per liter of chlorine at 10 minutes of contact (Table 14); in neither case did aftergrowths develop.

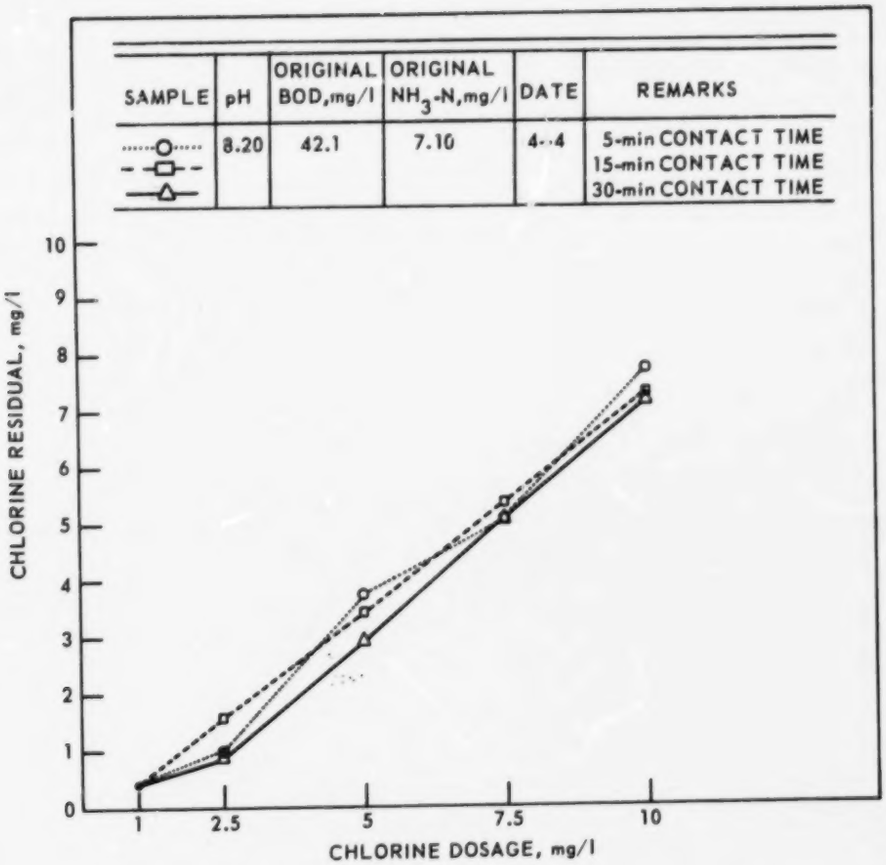

Figure 9. Chlorine dosage vs chlorine residual at 5–, 15–, and 30–minute contact times.

Table 14. COLIFORM IN EFFLUENT AFTER CHLORINATION, EXPERIMENT 2

Cl_2 applied, mg/l	Initial MPN/100 ml	Contact time				
		15 min	30 min	60 min	72 hr[a]	8 days[a]
		MPN/100 ml				
0	7,900					
1.0		13,000	4,900	22,000	13,000	7,900
2.5		7,900	1,700	2,300	330	700
5.0		490	330	790	130	20
7.5		490	20	45	20	20
10.0		20	20	20	20	20

[a] Aftergrowth evaluation.

These studies indicate that the effluent from the Lebanon stabilization ponds can be chlorinated effectively in the range of 7.5 to 10 milligrams per liter of chlorine with a minimum contact time of 15 minutes. Effective chlorination probably kills the algae and results in an increase of BOD in the range of 15 milligrams per liter. Apparently, BOD incubation does not destroy all the algae. Chlorine dosage at breakpoint does not provide effective bacterial control. This study emphasizes the critical need for more research on the effectiveness of chlorination, particularly as applied to waste treatment plant effluents.

FUNGI

Within the waste stabilization pond system, a wide variety of organisms occur; among them are the fungi, including both filamentous molds and yeasts. In the Lebanon waste stabilization pond area, 207 species of fungi were identified; two samples were taken about 18 days apart at each of 34 sampling stations during each of the four seasons of the year. Isolations were made by several techniques on a number of different types of media.

Based on the number of species isolated from each sampling station, the coefficient of similarity for every possible pair of stations was determined, and from the coefficients a two-dimensional ordination was prepared. The groupings for the 34 sampling points were found to be (1) raw sewage; (2) soil samples with relatively little disturbance; (3) sludges from the bottom of the four ponds near the influent pipe; (4) similar sludges but near the effluent pipes; (5) mid-pond waters; (6) pond effluents; (7) scums from the surfaces of the ponds; (8) bottom materials in the "streams" carrying effluents from the primary ponds; (9) water, water and sediments in pools and riffles, and bank soils in Shaker Creek above the ponds; and (10) similar materials from Shaker Creek below the ponds.

Yeasts appeared to be more abundant in pond waters and in all habitats that were always wet and organically enriched, whereas filamentous fungi were less prevalent in such habitats, except in pond sludges and scums. Within the liquid system, mid-pond waters and pond effluents more nearly retained the characteristic populations of raw sewage than did the other groups of habitats. Of the creek habitats sampled, only water in an area below the ponds appeared to contain spore loads similar to those in the raw sewage. Possibly this is because the water in the creek at this point was affected not only by wastes from upstream areas but also by seepage or runoff from the barns and by wastes from the kitchen of the dormitory. With this exception, stations on the creek appear to fall into two fairly dissimilar groups: those from the upstream sampling sites and those from the downstream sampling sites.

The remaining sets of habitats sampled appear to be similar, with respect both to the spora of raw sewage and to the populations of the undisturbed soil of the original habitat. Soils from the mouths of muskrat dens in the dike around Pond I and soils from the swampy areas in Pond V are very similar to undisturbed soil found in a fence row that is at least 40 years old, even though the former two types of soil are subsoils from below the plough line of the field from which the ponds were made and the samples from the fence row were taken from the upper 2 inches of soil.

The fungi found in this group of samples and those found in raw sewage appear to make up the populations found in the other four sets of communities. Based on the differences in bottom construction and seepage characteristics, the samples from each of these four habitats were somewhat dissimilar, and each of the four habitats forms a population relatively dissimilar from that of the others.

In the ponds, the number of fungal species increased from 40 prior to the beginning of the treatment operation to 207 at the end. The number of fungal colonies before the beginning of the treatment cycle was only a few thousand per gram of soil, but after the start of treatment the number jumped to an average of more than 250,000 per gram dry weight of sludges and liquids in April, 265,000 in September, 100,000 in November, and 990,000 in March. Except for November, when adverse conditions of undetermined nature, possibly related to wastes added to the ponds, reduced the fungal populations, these values indicate a favorable habitat for fungi. On this basis, it appears certain that fungi can be counted among those saprobic organisms that play a part in the removal of organic wastes from the waters of these waste stabilization ponds.

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James McDermott, now Chief, Water Resources Section, U.S. Public Health Service Region II, New York, was responsible for getting operations under way.

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Jules Cohen and Victor Jelen, Staff Engineers of the Technical Advisory and Investigations Section, designed and constructed the automatic raw-sewage sampling device.

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Robert McCullough, Staff Mechanic of the Technical Advisory and Investigations Section, was responsible for facility maintenance and for supervision of much of the field work during the approximately 4 years of operation.

Paul Jones and Melvin Curry, Staff Technicians of Technical Advisory and Investigations Section, supervised and assisted in the field work.

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Additional assistance and contributions were generously provided by others at the Robert A. Taft Sanitary Engineering Center.

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